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FUMIGATION STUDIES No. 6.

A NEW LEAKAGE GAUGE

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We have pointed out in several previous bulletins of this series the great importance of leakage in the determination of the correct dose in fumigating, but there has not been hitherto any practical method of determining the leakage. A new method has now been perfected by the use of a simple piece of apparatus, to be described in the present circular, whereby this determination can be made very quickly and accurately.

The apparatus is shown in Figs. 1 and 2. It consists of a clamp (*d*) by means of which a portion of the tent to be tested is firmly held in the apparatus and a set of three tubes, one of brass, ending in a nipple (*i*) for attaching a rubber mouthpiece, and the other two of glass (*b* and *c*) along one of which is a scale so graduated as to show the degree of leakage. All these tubes communicate with a small glass chamber filled with water.

The method of determining the leakage is as follows:

1. Unscrew the glass chamber (*a*) filling the glass part full of water, then replace it on the instrument. If properly filled, the water will not be seen in the glass tubes above the top of this chamber.

2. Clamp a fold of the tent to be tested in the instrument. The reason for testing a double thickness of the tent is that this enables one to test any part of the tent with equal facility. The gradations are planned for double tents and would not indicate the correct leakage for a single thickness.

3. Blow gently through the rubber tube till the water is seen to rise in one or both of the glass tubes, blowing hard enough to bring the water to the top of one of them, and read the degree of leakage on the scale where the top of the column of water reaches in the other tube.

The earlier studies of the processes of fumigation are as follows:

1. Orchard Fumigation, Bulletin 126.
2. Fumigation Dosage, Bulletin 152.
3. Fumigation Practice, Circular 11.
4. Fumigation Schedule, Circular 50.
5. Dosage Tables, Bulletin 220.

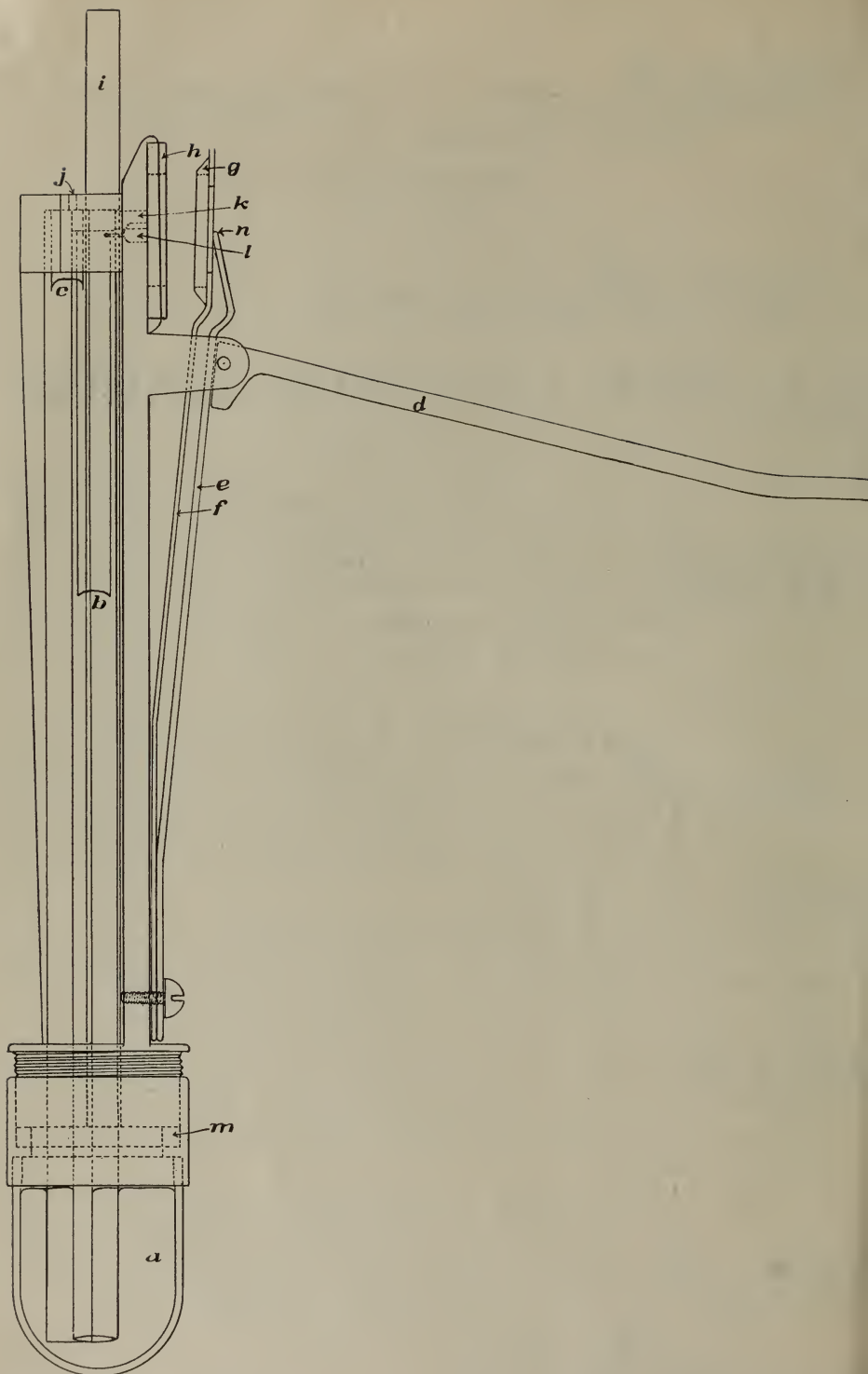


FIG. 1.—The new leakage gauge. *a*, water reservoir; *b*, gauge tube with water column at "test" height; *c*, open gauge tube showing water column at top; *d*, clamp lever; *e*, outer clamp spring; *f*, inner clamp spring; *g*, clamp ring; *h*, rubber washer; *i*, nipple of brass tube; *j*, opening to open gauge tube; *k*, passage to closed gauge tube; *l*, passage to brass tube; *m*, washer of reservoir.

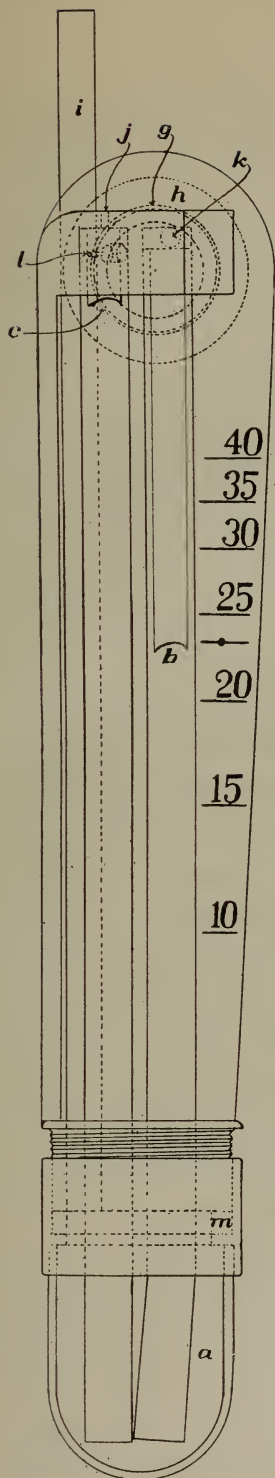


FIG. 2.—The new leakage gauge; face view showing graduations. The lettering the same as Fig. 1.

4. The dose of cyanide, which should be used to correspond with the degree of leakage found by this apparatus, is obtained by the methods given in detail in Bulletin 220.

THEORY OF LEAKAGE GAUGES.

While the above directions are all that is necessary to understand in order to obtain accurate dosage, it is desirable that the user should understand the principles upon which the apparatus is based and the details of its construction.

The theory upon which all methods of measuring leakage is based is, that the rates of leakage of gas through different pieces of cloth will show approximately the same difference that is found between the rates of flow of air through these cloths, when it is forced through under the same pressure; thus, if under identical conditions one litre of air will pass through one piece of canvas while two litres pass through another, the second is assumed to permit the escape of the cyanide twice as rapidly as the former.

There are two practical methods of determining the rate at which air will flow through a piece of cloth. The one first used in our experiments, and the only one used by other experimenters, was to measure the volume of air passing through in a given time, or more often the time required for a definite volume to pass, the pressure forcing the air through the cloth, of course, must be maintained uniform in making such determinations. The method utilized in the apparatus here described is, to measure the resistance to the passage of the air presented by the cloth to be tested as compared with an opening of a known size. The particular advantage of this second method is the simplicity of the apparatus and the rapidity of the determinations.

METHOD OF STATING LEAKAGE.

Heretofore the relative leakage has been stated in terms of quantity of air per minute or of minutes per given quantity and must be inter-

puted by noting the size of the area tested and the pressure. A very much more rational method is by the use of percentages. The method of determining the per cent of leakage is as follows: The apparatus used in measuring the leakage in our first experiments consisted of a vessel holding a litre of water, closed except for two openings, a larger one below for the escape of the water and one above for admission of air. Over this latter opening was clamped a sample of the cloth to be tested. The water would run out as fast as the air could flow through the section of the tent being tested to replace the water. The time is determined by the use of a stop watch. By allowing the air to enter through a small hole of a known size, instead of through the cloth, the time required for a litre of air to pass could be similarly determined. This was done repeatedly during the course of our experiments with holes of various sizes, and in this way a formula was developed for calculating the rate of flow through holes of any desired size. It is then but a simple matter to calculate the ratio between the area of the sample of the canvas held in the clamp for testing, and of a hole of a definite size to obtain the percentage. In the average fumigation tent, according to our determinations, an equivalent hole was found to be one four hundredths part of the total area of the sample, giving a leakage therefore of one quarter of one per cent. The leakage through a piece of tent cloth two inches square (4 sq. in.) would in an average fumigating tent be equivalent to a single hole one tenth of an inch square. The total amount of leakage will depend upon the leakage surface, and the same tent will give a varying amount of leakage whether on a large or a small tree. The proportion of gas that escapes from a tent will vary also with the size of the tree covered, since the large space contains a greater volume within each unit of surface. The percentage of leakage corresponds with total leakage or with the proportionate loss of gas only when the volumes are equal. The same tent will vary according to the conditions of the weather. When the fibres are swollen by absorbing moisture the spaces are of necessity smaller and the leakage is correspondingly diminished, on the other hand when the air is very dry the fibres shrink leaving larger interspaces and the leakage becomes greater. Thus, the same tent may show a different per cent of leakage at different times.

It will be necessary to determine by means of the leakage gauge the exact amount of this change and then from the proper dosage table, given in Bulletin 220, one can determine the correct dose, thus insuring uniform strength of gas within the tent to the end of the killing period.

LEAKAGE IN TORN TENTS.

We are now able for the first time to estimate the effect of working with a tent which has been snagged or torn, and compare it with the changes in leakage due to the character of the cloth or to the condition

of the weather. It is entirely possible for a tent to be full of conspicuous holes and still be tighter than a new tent with a looser weave of canvas.

The leakage gauge is marked off into divisions corresponding with 0.05 per cent of leakage. The following table shows the number of square inches corresponding with this amount of leakage in tents of various sizes:

TABLE I.
Size of holes corresponding to 0.05 per cent leakage.

Size.	Leakage area.
17 feet-----	17 square inches.
24 feet-----	33 square inches.
30 feet-----	52 square inches.
36 feet-----	75 square inches.
41 feet-----	87 square inches.
43 feet-----	107 square inches.
45 feet-----	117 square inches.
48 feet-----	133 square inches.
52 feet-----	156 square inches.
55 feet-----	175 square inches.
64 feet-----	237 square inches.
72 feet-----	300 square inches.

The aggregate of 107 square inches of holes in a tent 43 feet across allows a leakage of only 0.05 per cent or only a fifth of the average degree of leakage due to the weave of the cloth.

Fumigators are very watchful, and properly so, for holes in the tent, but ignore the variations of leakage through the weave of the cloth, which may often be of very much greater importance.

In the case of a 43-foot tent the average leakage is equivalent to holes having an aggregate area of 535 square inches (5 times 107). The difference of leakage on a very dry night will equal at least 214 square inches additional, or a total of 849 square inches. Any inspector would condemn a tent with half a dozen tears big enough to put one's fist through, while their average area might not exceed three square inches, or a total increased leakage not over one tenth of the 214 square inches of additional leakage due to dryness.

There is no doubt of the importance of looking for and mending the tears of a fumigating tent, but it is more important, and very much more important, to measure the leakage of the cloth.

In the above table we have supposed that the holes were evenly distributed, but since they usually occur in the center portion of the tent rather than in the skirt, a more satisfactory manner of estimating its amount is by figuring the portion of the tent off the ground, as is done in Table II. The amount in this case varies with the size of the tree as measured by the distance over the top. Some of the leakage may be decreased by the folding of the cloth down the sides, and therefore the leakage of a tent made just to fit the tallest shaped trees (bell-shaped) is given to show the smallest possible leakage. A bell tent on a low, broad tree would be much more like a sheet tent.

In any case, a greater leakage can be offset by increasing the dose. If, for instance, a tent on a tree measuring 30 feet over the top which showed a leakage of 0.2 per cent by the gauge, but which had one or more tears amounting to about 51 square inches in area, one should use the 0.25 per cent table for determining the dose. The same tent on a previous night before it was torn might have shown 0.3 per cent leakage, and required the use of the still larger dose given in the 0.3 per cent table.

TABLE II.

Size of holes corresponding to 0.05 per cent leakage.		
Distance over.	Bell tent.	Sheet tent.
10 feet.....	2.95 square inches.	5.66 square inches.
12 feet.....	4.24 square inches.	8.16 square inches.
14 feet.....	5.78 square inches.	11.10 square inches.
16 feet.....	7.54 square inches.	14.46 square inches.
18 feet.....	9.54 square inches.	18.33 square inches.
20 feet.....	11.80 square inches.	22.65 square inches.
22 feet.....	14.25 square inches.	27.40 square inches.
24 feet.....	16.95 square inches.	32.60 square inches.
26 feet.....	19.90 square inches.	38.30 square inches.
28 feet.....	23.10 square inches.	44.40 square inches.
30 feet.....	26.55 square inches.	51.00 square inches.
32 feet.....	30.20 square inches.	58.00 square inches.
34 feet.....	34.50 square inches.	65.40 square inches.
36 feet.....	38.20 square inches.	73.40 square inches.
38 feet.....	42.60 square inches.	81.60 square inches.
40 feet.....	47.20 square inches.	90.60 square inches.
42 feet.....	52.00 square inches.	99.80 square inches.
44 feet.....	57.00 square inches.	109.50 square inches.
46 feet.....	62.20 square inches.	119.50 square inches.
48 feet.....	67.90 square inches.	130.40 square inches.
50 feet.....	73.60 square inches.	141.30 square inches.
52 feet.....	79.60 square inches.	152.80 square inches.
54 feet.....	85.90 square inches.	165.00 square inches.
56 feet.....	92.40 square inches.	177.50 square inches.
58 feet.....	99.20 square inches.	190.50 square inches.
60 feet.....	106.00 square inches.	203.70 square inches.
62 feet.....	113.30 square inches.	217.60 square inches.

THE TENT CLAMP.

In our first experimental work we used the method which has also been employed by others, of tying the sample to be tested over the end of a pipe. We soon appreciated, however, that for practical use in the field we needed a clamp that could be instantly applied and experimented with a number of forms.

The first satisfactory form of clamp is shown in Fig. 3. It consists of two cups (*d* and *e*) held together by a strong spring (*a*) and opened by a pair of arms (*b* and *c*) acting as levers, pulling the cups apart to insert or remove the cloth being tested.

The cups are attached loosely to the arms and adjust themselves when closing over the cloth. The cavity of one cup is smaller than that of the other, and the rim of the larger rests against the rounded outer edge of the other, stretching the canvas tightly against the rim of the smaller cavity. The smaller cavity connects with a nipple (*f*)

and the larger one is open beneath. In operating, the nipple gives attachment by means of a rubber tube to the other part of the apparatus, and air can be drawn or blown through the portion of the cloth held in the clamp.



FIG. 3.—Tent clamp. *a*, spring; *b* and *c*, levers to open clamp; *d* and *e*, clamp cups; *f* nipple.

In designing this clamp I am indebted to Mr. E. J. Hoff, mechanician of the U. S. Irrigation Investigation, for the working out of many of the details, and I have had his very efficient coöperation in all the mechanical work connected with this study.

The form of clamp finally adopted consists of a cup of metal large enough to hold an ordinary rubber hose washer (Fig. 1*h*) having an inside diameter of five eighths of an inch, or an area of nearly .4 of a square inch.

Over this projects the end of a strip of brass (*f*) bearing an annular extension (*g*) on its inner face, corresponding to the inner edge of the rubber washer. The portion of the strip within this annular extension is cut away. When a piece of cloth is inserted between the rubber washer and this strip, and the latter clamped down upon it, air may be forced into or from the cup through the area of the cloth within the ring of the clamp approximately four tenths of a square inch.

A second spring of spring brass (*e*) ending exactly opposite the center of the cup is so bent as to bear against the first strip. Above this second strip a lever (*d*) is arranged to exert the necessary pressure. These two strips are so bent that the clamp is equally tight on all sides. This can be determined by placing a thin piece of

paper over a folded piece of cloth in the clamp and noting, when removing it, if the paper is creased equally strongly at all points in the circle. If the lever were directly upon the first strip, it could only be adjusted for cloth of uniform thickness, and if the cloth were thicker than that

for which the instrument was adjusted, it would be gripped more tightly on the side nearest the clamping lever, and if thinner, it would be tighter on the opposite side, but, with the condition described above, the clamp works with all thicknesses of canvas without an appreciable difference of compression on either side.

The clamp first described remains normally closed by the action of the spring and needs no attention while making the test. The latter clamp remains open or closed according to the position of the lever, leaving both hands free, both while adjusting the cloth and while determining the leakage.

THE NEW PRESSURE GAUGES.

The clamps described above may be used for either method of determining the leakage. The determination of leakage by the volume method requires the use of rather bulky apparatus to provide for the displacement of a sufficient volume of air, and also the use of sufficient time to accurately gauge the difference between leakages, and means for maintaining uniform pressure during that time.

For these reasons an entirely new principle was adopted as a substitute for the "volume gauges," furnishing a class of apparatus which may be called "pressure gauges."

If air is forced through a tube narrowed at intervals by equal constrictions producing a series of chambers, A, B, C, D, etc., it is evident that an equilibrium will be quickly secured in which the quantity and the velocity of the air passing through each of these constrictions will be equal. Since the openings are all of the same size, this equality can only occur when the difference in the pressure of the air in the succeeding chambers is equal. Thus, if the pressure in A is ten pounds to the square inch and that in B is 9 pounds, then the pressure in C is 8 pounds, in D 7 pounds, etc., giving a difference of one pound.

If the constrictions are not of uniform size, since the same quantity must still pass through all the openings, it is clear that it must pass more rapidly through the smaller openings; or, in other words, the difference of pressure on the two sides of the smaller opening must be larger. If, for instance, the constriction between B and C is larger than through the others and that between C and D smaller, the pressures in the various chambers might be 10, 9, $8\frac{1}{2}$, and 7, showing only half a pound between B and C and a pound and a half between C and D.

If the size of one of the constrictions is known in such a series and we have the means of measuring the pressure in the various chambers, it will be rather a simple mathematical calculation to determine the size of all the other constrictions.

The pressure gauges are based on these well known physical laws and can be constructed with any degree of sensitiveness and in various

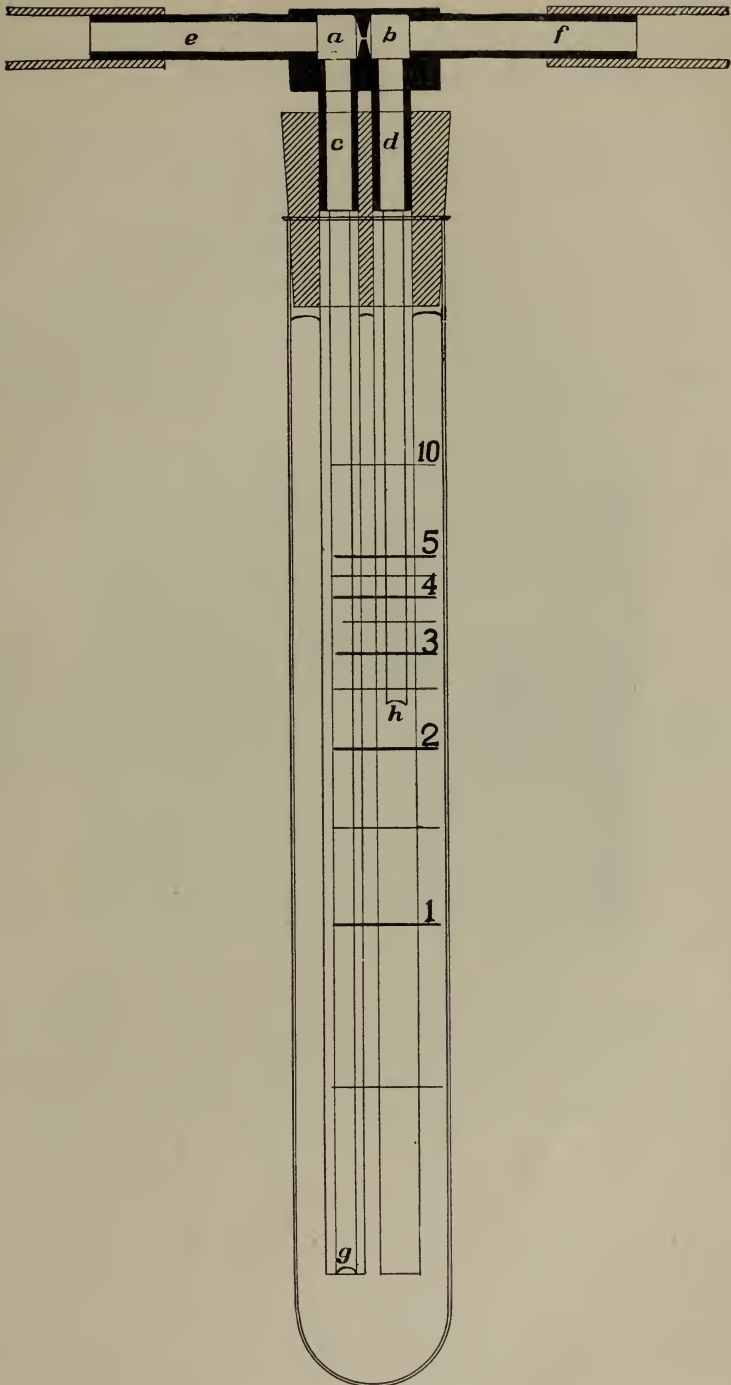


FIG. 4.—Test tube gauge. *a* and *b*, pressure chambers; *c* and *d*, gauge tubes; *e*, nipple leading to mouthpiece; *f*, nipple leading to tent clamp; *g*, air column at end of gauge tube; *h*, air column showing .24 per cent leakage.

forms. We will describe two used in our experimental work as well as the one recommended for practical field uses, though several other forms were tried and discarded for one reason or another.

TEST TUBE GAUGE.

A form of leakage gauge found very satisfactory in practice which was of about the simplest possible construction (Fig. 4) consists of two chambers (*a* and *b*) connected by a very small hole, each provided with two tubes, one from each (*c* and *d*) dipping deep into water contained in a test tube and the others (*e* and *f*) leading, one to the tent clamp and the other to the mouth of the operator. After attaching the clamp to the tent one blows through the instrument, and the pressure of the air in the two chambers is shown by the length of the air column in the tubes in the water in the test tube.

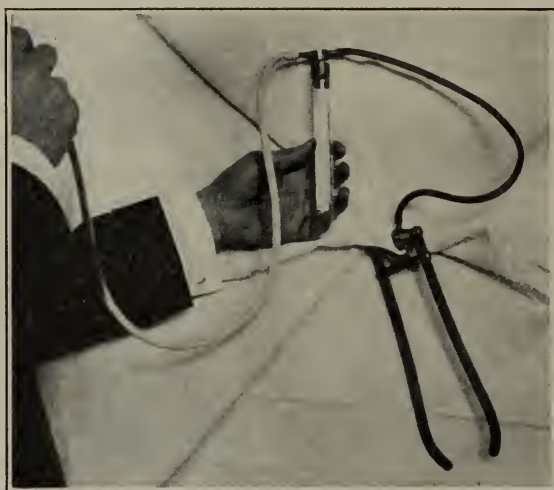


FIG. 5.—Operation of tent clamp and test tube gauge.

The amount of pressure to be used is just sufficient to force the air to the end of one tube (*g*) and a scale is provided whereby the amount of leakage in per cents may be read directly from the position of the air in the other tube (*h*). The tubes extending into the water must be of glass in order to see the position of the air columns. The scale is made on paper and fastened "face to" on the outer surface of the test tube. When the test tube is filled with water the scale is very easily read. The chief precaution in using this form of gauge is to always fill the test tube to the same level.

THE SUCTION GAUGE.

Exactly the same apparatus was used in the laboratory with the exception that a vacuum air pump was used instead of blowing through the apparatus and instead of dipping the glass tubes deeply into water,

only the ends were beneath the surface (Fig. 6). The suction from an air pump drew air through the cloth in the clamp and lifted the water up the glass tubes instead of forcing the air down. Also, the tubes were made much longer so that readings could be made to hundredths of a per cent. This plan is more accurate also, because a large dish of water may be used, and the level will not change appreciably with much or little leakage.

The amount of suction was just sufficient to raise the water column in one tube to the zero point and the per cent of leakage read on a scale along the other column.

THE REGULATING CLAMP.

It was necessary to construct a clamp whereby the amount of suction in the suction gauge could be regulated very accurately. The clamp shown in Fig. 7 gives perfect control of the suction. It consists of two pieces of half inch strap iron, with a screw at each end of the lower piece (*b*) fitting loosely in the upper piece (*a*). One screw is long, and has a clock wheel soldered to the head (*e*). Along the center of the lower face of the upper piece a short piece of wire (*c*) is soldered

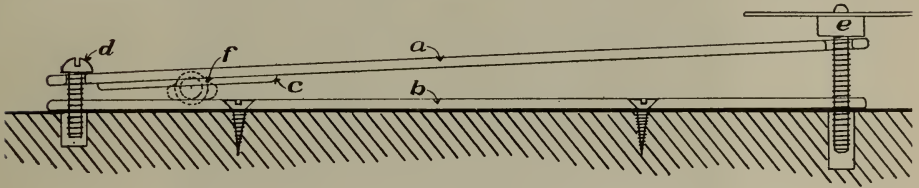


FIG. 6.—Operation of suction gauge testing a sample of tent material.

near the end containing the short screw (*d*). The rubber hose (*f*) is compressed beneath this wire.

The clamp is adjusted approximately by means of the small screw, using a screwdriver, and then accurately by the large screw, which works by hand. When ready to operate the test the hand screw is turned down, completely closing the rubber suction tube, then the cloth is placed in the tent clamp and the screw turned up slowly until the water column in one tube reaches the zero point. The column can be held perfectly steady at this point while the reading is being taken on the scale along the other column.

GRADUATING THE SCALE.

When there is no leakage both columns will move in an identical manner and both will reach the point selected as the zero point. With 100 per cent leakage, that is, with nothing in the tent clamp, only one column will move at all, the surface of the water being the 100 per cent. Between 0 and 100 per cent the scale can be most easily made by the use of a curve constructed in the manner described below.

1. Draw a line as long as the distance from the 0 to the 100 per cent point, at the 100 per cent end draw a base line perpendicular to the other.

2. Place a disc in the tent clamp having a hole of a known size and find the point on the gauge tube which indicates the resulting leakage. Plot this point on the line being graduated.

3. Calculate the area of the hole in the disc and divide this amount by the area of the cup of the tent clamp. Draw a line from the leakage point previously determined parallel with the base line, and lay off

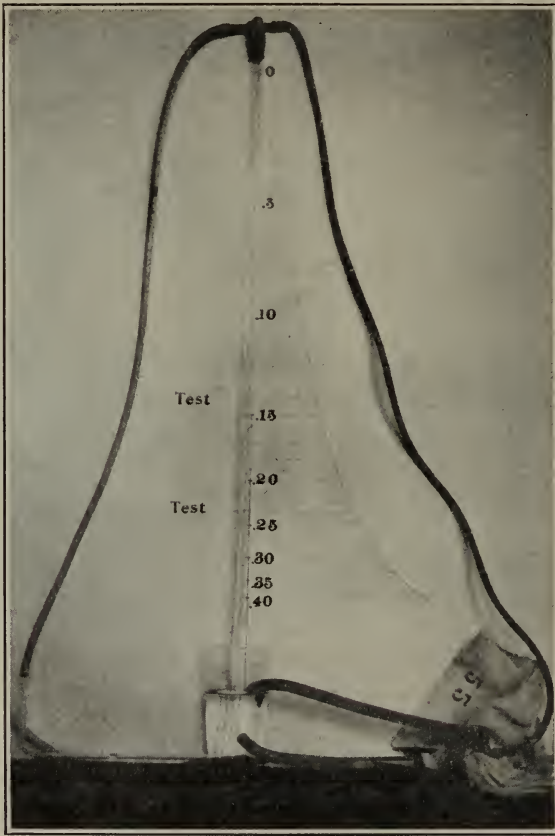


FIG. 7.—Regulating clamp. *a*, upper bar; *b*, lower bar; *c*, compression blade; *d*, coarse adjusting screw; *e*, fine adjusting screw; *f*, rubber tube being compressed.

along this line a distance corresponding with the per cent of leakage area just calculated.

4. Repeat items three and four with at least one other hole of a different size.

5. Draw a curve beginning at the zero point and passing through the points just laid off and approaching the base line, but not actually reaching it.

6. Draw a series of lines at right angles to the base line at distances corresponding to hundredths of a per cent for instruments with long columns, or, .05 per cent for the ordinary short field gauges.

7. Where these per cent lines intersect the curve, draw lines parallel to the base line, intersecting the first line drawn, and these are the graduation points for the instrument.

Fig. 8 shows the gradations used in the suction gauge and illustrates the method of graduation described above.

The instrument should be so constructed that the ratio of area between the constriction and the cup of the tent clamp should correspond approximately with the average leakage of the tents to be tested. Since we desire to test this cloth doubled, allowance must be made for this fact, and the area of the tent clamp should be about 700 times that of the constriction or $26\frac{1}{2}$ times as large in diameter. The drill used for the small hole in the instruments used in this study was .6 mm. in diameter. This will bring the readings of the commonest leakage near the center of the scale.

THE COMBINED APPARATUS.

The form of leakage gauge which we are recommending combines the tent clamp and the gauge in one machine (Figs. 1 and 2). The structure of the clamp has already been described above. The gauge differs from either of the forms just described by the fact that the pressure from the first chamber is communicated to the surface of the water reservoir which would drive the water up both gauge tubes alike, except for the back pressure in one of the gauge tubes.

The reservoir (*a*) which is a glass or metal cup, is screwed fast to the end of the instrument and into it extends the two glass gauge tubes. A brass tube (*i*) to which the rubber mouthpiece is attached also opens into this chamber, but does not dip beneath the water. One of the glass tubes is open above to the outside air (at *j*), the other opens into the cup of the tent clamp (at *k*). This brass tube connects by a very small hole (*l*) with the cup of the tent clamp which forms the second chamber of the apparatus.

THE TESTER.

The leakage gauges are not liable to get out of order, but if dirt or water gets into the small hole connecting the two chambers, the results will be too high, that is, the tents will appear to be more leaky than they really are.

A small disc of brass should therefore accompany every instrument to use as a tester, and a special line on the scale will show the point at which the water should stand in the gauge tube when the tester is placed in the clamp. The hole in the tester should be clean since the presence of any dirt will cause the column of water to stand nearer the zero point.

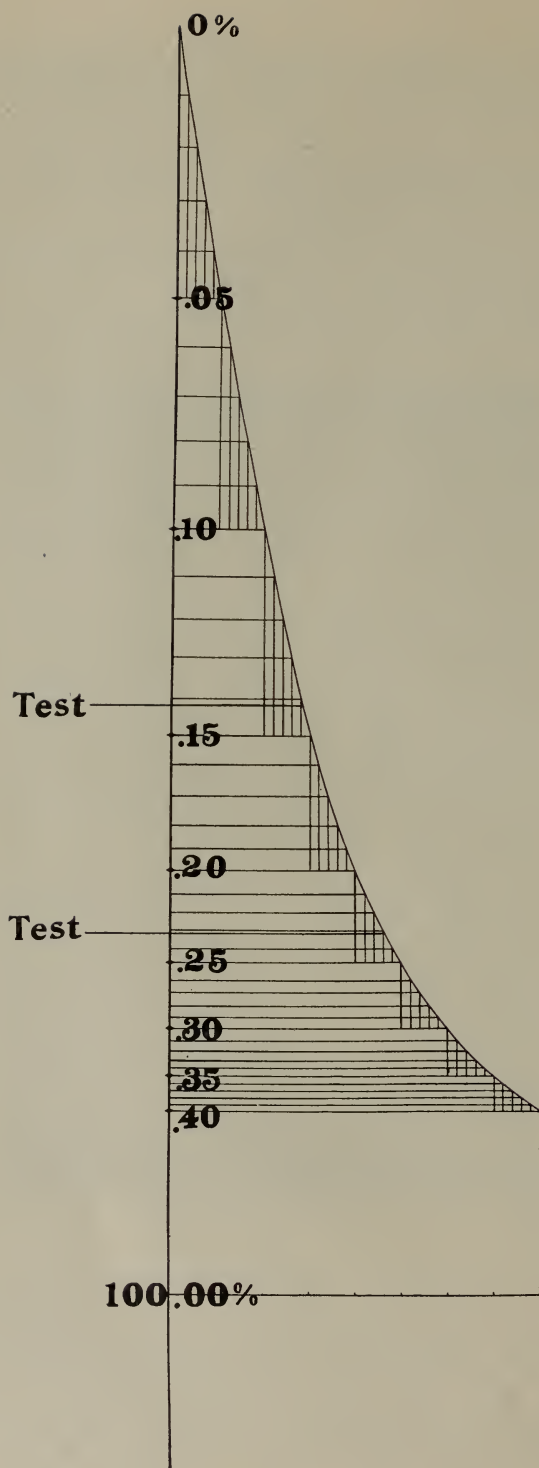


FIG. 8.—Scale showing method of gradation.

Either of these holes may be cleaned by using a wooden toothpick, but no metal should be used for fear of permanently enlarging the holes. The accuracy of the instrument depends upon the small hole connecting the chamber remaining the same size. If for any reason the instrument will not give the correct reading with the tester, it may be sent to the maker for adjustment.

RÉSUMÉ.

This Circular gives directions for using a leakage gauge on fumigation tents.

The theory of leakage determination is explained.

The use of per cents to express the leakage of tents is the most rational method.

Leakage through the weave of the cloth is much more important than that through visible holes, and the necessary adjustment of the dose for either is illustrated.

Different forms of tent clamps are described.

Pressure gauges for determining leakage are more practical than volume gauges.

A test tube gauge is the simplest form of pressure gauge.

A suction gauge is the form most satisfactory in the laboratory and requires a special form of regulating clamp.

The method of graduating leakage gauges is explained.

A combined instrument, containing both tent clamp and gauge, is recommended for field work.

The use of a tester enables one to be sure of the proper adjustment of the instrument.

